TECHNICAL MEMORANDUMS

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

No. 556

THE ELECTRODYNAMOMETRIC BALANCE OF THE SMALL WIND TUNNEL OF THE FRENCH SERVICE OF AERONAUTICAL RESEARCH

By P. Rebuffet

Lecture delivered before the "Societe de Navigation Aerienne"
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The small wind tunnel of the "Service des Recherches de l'Aéronautique" is the last one constructed in the service. It was finished in 1927. It is of the Eiffel type with a closed chamber and a free jet. The diameter of the jet in the experiment chanber is 1.8 m (5.91 ft.). The maximum velocity of the air stream is 50 m (164 ft.) per second.

The model to be studied is suspended in the tunnel by a system of wires. These wires are put under an initial stress, so as to give the model a certain fixity. Under the action of the aerodynamic pressure developed about the model, some of these wires undergo variations of stress, which are measured by means of dynamometers. The magnitude and direction of the aerodynamic resultant are calculated from these measurements.

It was desired to have a recording balance for the small wind tunnel, which would provide a permanent record of the tests made. Mr. Villey had previously explained the principle of the electrodynamometers, which seemed to him to have solved this problem in a remarkable way (See Journal of Physics, Octo-

*A lecture delivered before the "Société de Navigation Aérienne" (Air Navigation Society) June 5, 1929, a copy of which was obtained by the Paris Office of the N.A.C.A.

ber, 1927). I was given the task of perfecting them. The work was begun in the physical laboratory of the S.T.I.Aé. (Service Technique et Industriel de l'Aéronautique). At this period of the researches there intervened the period of installation of the small wind tunnel and the changes necessitated by the new conditions of utilization. This latter work was done in 1927-28 with the collaboration of Mr. Girault, at that time an engineer in the S.T.I.Aé.

I will explain briefly the principle of Villey's electrodynamometers. They are variable-capacity instruments. The force to be measured acts on a flexible steel plate which is placed in front of a fixed plate. The deformation varies the original thickness of the layer of air between the two plates, thus causing a more rapid variation in the coefficient of electrostatic attraction of the two plates than in the capacity of the condenser formed by the dynamometer.

The measurements are made by a differential method. The capacity of the test dynamometer is compared with that of a similar instrument of constant capacity, this comparison being made by means of an electrometer. I will show diagrams of the dynamometer, the electrometer and the electrical connections.

Figure 1.- This shows a sectional view of the dynamometer and the massive block to which the flexible plate is bolted. The fixed electrode is inside the block. It is mechanically

secured to the block, but is electrically insulated by sockets of "orca."

Figure 2.- Photograph of a dismantled dynamometer. The different parts are apparent. Note the support of the eyebolt in the form of a clamp in which the plate is held.

Figure 3.- Views of an electrometer. We see, on the longitudinal section, the quadrants formed by four wires stretched along the edges of a prism of square section. They are arranged in pairs of wires diametrally opposed. Inside the wires, the "needle" consists of a small rectangular brass plate suspended by a torsion wire with a tail supporting a mirror, and a damping plate in an oil bath. The instrument is completed by a base with tightly fitting screws.

Figure 4.- Electrical connections. The electrometer and the two dynamometers are shown diagrammatically. An alternating voltage is impressed between the dynamometer block and the electrometer needle. The wire connecting the active electrode of the dynamometer to the quadrants of the electrometer is subjected to exterior electrostatic influences. Hence it passes through a tube which constitutes a Faraday shield.

If the capacities of the dynamometers C_1 and C_2, as well as of the lines, are equal, the potentials V_1 and V_2 at the terminals of the electrometer are also equal. The movable part

will therefore remain at zero. If the capacity C_1 varies, V_1 varies likewise and the electrostatic couples on the needle differ, causing it to rotate. It is easy to establish the law which shows the relation between the rotations θ of the needle and the variations $d\,e$ of the layer of air in the dynamometer.

The principal difficulties met in the installation of these electrodynamometers in the small wind tunnel were as follows:

I. Mechanical problems.- The first difficulty of a mechanical nature concerns the return of the flexible plate of the dynamometer to zero. It is necessary for the deformation of the plates to be perfectly elastic. It does not suffice to make the plates work at a low mean rate of fatigue. It is also necessary to have no abnormal stresses at any point of the plate. In the first dynamometers, the eyebolt was screwed directly to the plate, the force being exerted therefore by the screw heads, causing conditions of great local fatigue. We were obliged to eliminate all fastening screws and secure the plate to the eyebolt support by a clamping device. The thickness of the plates corresponds to the magnitude of the forces to be measured. In the small wind tunnel the forces reach 3-8 kg (6.6-17.6 lb.) according to the dynamometers, whence a thickness of 1.5-2 mm (0.059-0.079 in.), the maximum deformations of the plates being about 0.2 mm (0.008 in.). Hence, aside from the facility of photographic recording, the first advantage of these dynamome-

ters is that they constitute veritable fixed points to within about 0.2 mm. This is a remarkable quality, since any displacement of the point of application of the forces entails a displacement of the model.

Another mechanical difficulty proceeds from the vibrations. They are produced by the running of the tunnel and by the engine which drives the suction fan. It is necessary that these vibrations have no effect on the position of the electrometer light spots. The table supporting the electrometers rests on a concrete foundation insulated from the ground by a space filled with granulated cork. A sheet of felt placed under the electrometer constitutes a good shock absorber.

II. Electrical problems.- One of the first problems was the establishment of the connecting lines between the dynamometers and electrometers. These lines average about ten meters (33 ft.) in length. It is necessary for the active conductor to be perfectly insulated. The wire is stretched along the axis of a tube. The connections of the different tubes are themselves protected by short sections of tubing. The capacities of the lines affect the equilibrium of the two circuits of the test and comparison dynamometers. Since the lengths are not the same, it is necessary to make the elements of greater linear capacity.

An important point is to determine the kind of current to use. An alternating current is used, in order to eliminate the

difficulties due to leakage and to defects in the insulation. The frequency of fifty cycles per second has been found insufficient. A frequency of one thousand cycles per second should be used. The current is produced by a small auxiliary group. The voltage used should be perfectly constant, in order to keep the sensitivity constant during the test. The Vernotte voltage regulator has been found indispensable (Comptes Rendus de l'Academie des Sciences, July 12, 1926).

The arbitrary sensitivity variations of the dynamometers, according to the forces to be measured, are obtained by varying the potential applied to the dynamometer. They can therefore be very easily obtained instantaneously. Here is a second advantage of these dynamometers. By the simple operation of a rheostat or switch, there can be given to all the dynamometers simultaneously, or to each one separately, the desired sensitivity with respect to the force to be measured.

III. Thermal problems.- The temperature variations have attracted our attention by their possible effect on the dynamometers and electrometers. It concerns the temperature variations during a test. They are caused by the motor driving the propeller (which plays the role of radiator) and by the fact that the indrawn air is not at the temperature of the wind tunnel. The differences are only a few degrees, however.

On the dynamometers, the effect of temperature variations

has not been determined. It is probable that the body and the plate of the dynamometer have very similar coefficients of expansion. On the electrometers the temperature variations cause a variation in the position of equilibrium of the mechanism, seemingly due to the effect of the temperature on the torsion wire and to certain capillary effects in the oil cup. We can overcome these disadvantages by placing the electrometers in a box insulated by means of cork.

Another important point is to protect the dynamometers from metal or other dust, which gets inside the dynamometer, between the two plates. This causes short circuits or, at least, considerable variations in the capacity. A silk cover has been found very efficaceous.

I will now show photographs of the installation.

Figure 5.- Suspension of a model. We can see the vertical suspension wires fore and aft of the model which is attached at three points. The variations in the tension of these wires give the vertical component, or lift, of the resultant. The horizontal wires give the horizontal component or drag. The moment of the resultant with respect to the leading edge is obtained from the knowledge of the stress in the after wire.

Figure 6.- (Continuation of the lower part of Figure 5).- The forward wires end at a bar attached to the two forward lift dynamometers. Likewise the after wire is attached to a dynamom-

eter. This dynamometer is mounted on a frame which makes it possible to vary the angle of attack of the model. The plane of the three attachment points of the model being parallel to that of the frame, we thus obtain a jointed parallelogram. Note, on the photograph, the attachments of the connecting lines, that of the after dynamometer being articulated.

Figure 7 (Continuation of the upper part of Figure 5).- The wires end at the balance beams. The weights placed in the scale pans counterbalance the weight of the model and impart an initial stress to the lower wires. They likewise enable the calibration of the dynamometers to be made.

Figure 8.- We see the horizontal wire ending at the drag dynamometer. This dynamometer is fixed on a vertical axis mounted on ball bearings and moves following the direction of the wire. Note the attachment of the connecting wire.

Figure 9.- A general view of the recording installation on the ground floor. In the left foreground is the box containing the dynamometers, showing the ends of the lines. Back of these are the comparison dynamometers and their lines. In front of these is the reel of photographic paper for receiving the rays reflected by the electrometers.

Figure 10.- Inside of electrometer box.

Figure 11.- View of an instrument of the same principle used for recording the wind velocity. A thin metal diaphragm, situated in front of the fixed electrode, separates the wind-tunnel room from the experiment chamber. The pressure difference in the exit cone, except losses of pressure head, is equal to the term $\frac{\alpha V^2}{y}$ of Bernoulli's equation, whence the velocity is known from a preliminary calibration.

Figure 12.- Photograph of a test film. First part: calibration of dynamometers. Known stresses are imposed and the corresponding deviations of the electrometer light spots are recorded. The calibration of the vertical and horizontal wires is made successively in such a way as to show on the film the defects (if any) in the adjustment of the suspension wires and eventually to make the corrections. The calibration takes from 15 to 20 minutes.

Figure 13.- Second part of film. This shows the different positions of the light spots for each angle of the model in the wind. The slight undulations in the lines are due to variations in the velocity of the air. The mean is indicated. Duration of test was about ten minutes. The time covered by these films was, unfortunately, a little long (about two hours).

Precision of these tests.- Systematic tests, made with the instrument which served for investigating the conditions of in-

stallation, show that a precision of 0.002 to 0.003 of the maximum force measured can be attained. For the whole installation, it may be estimated that a precision of 0.5 to 1% is attained. This installation has been used for the tests made in the small wind tunnel during the past year.

Translation by Dwight M. Miner,
National Advisory Committee
for Aeronautics.

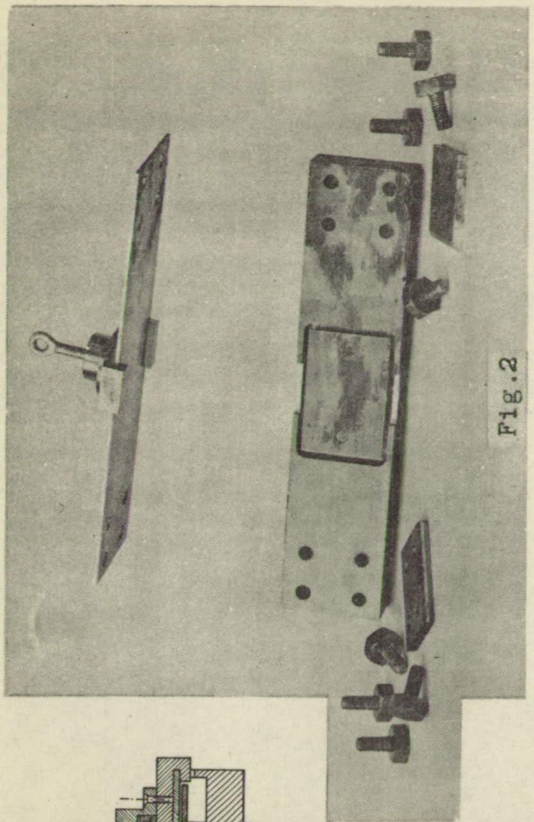


Fig.2

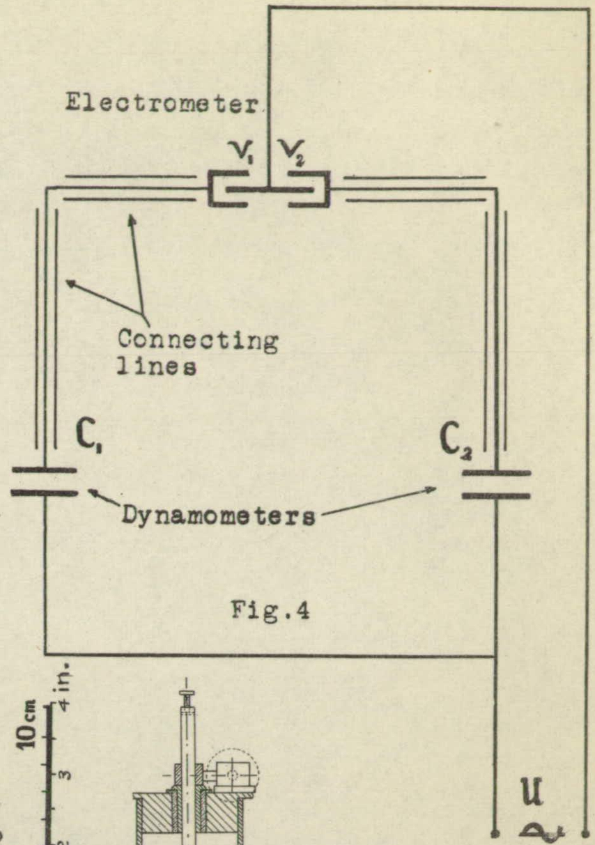


Fig.4

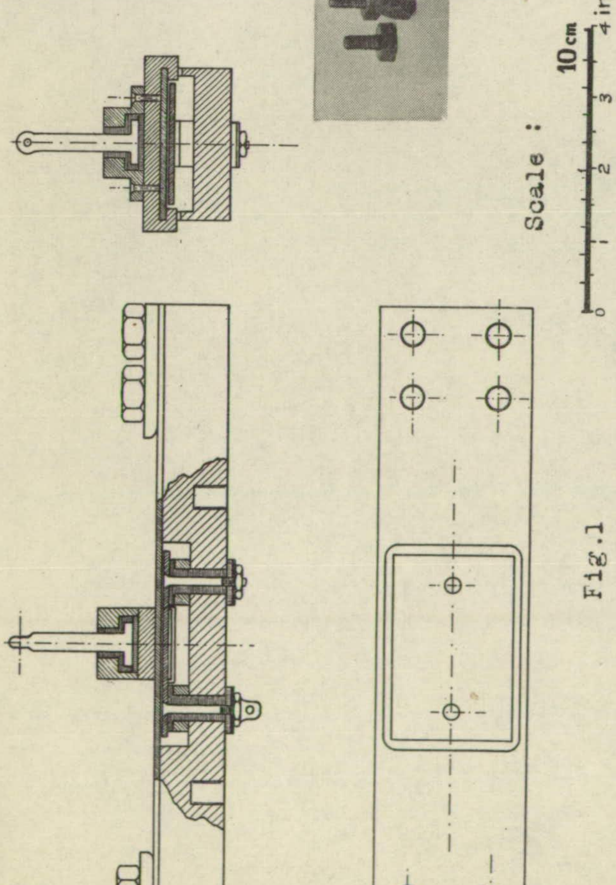
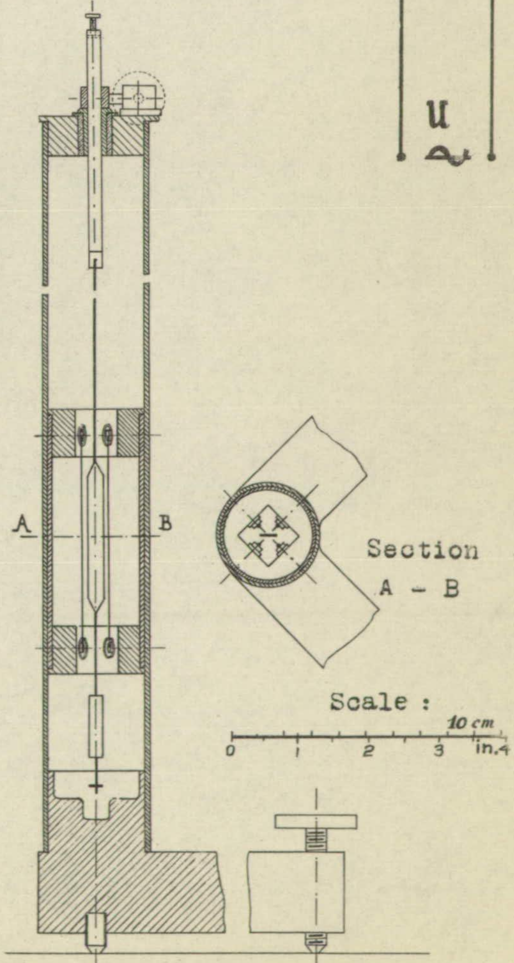


Fig.1



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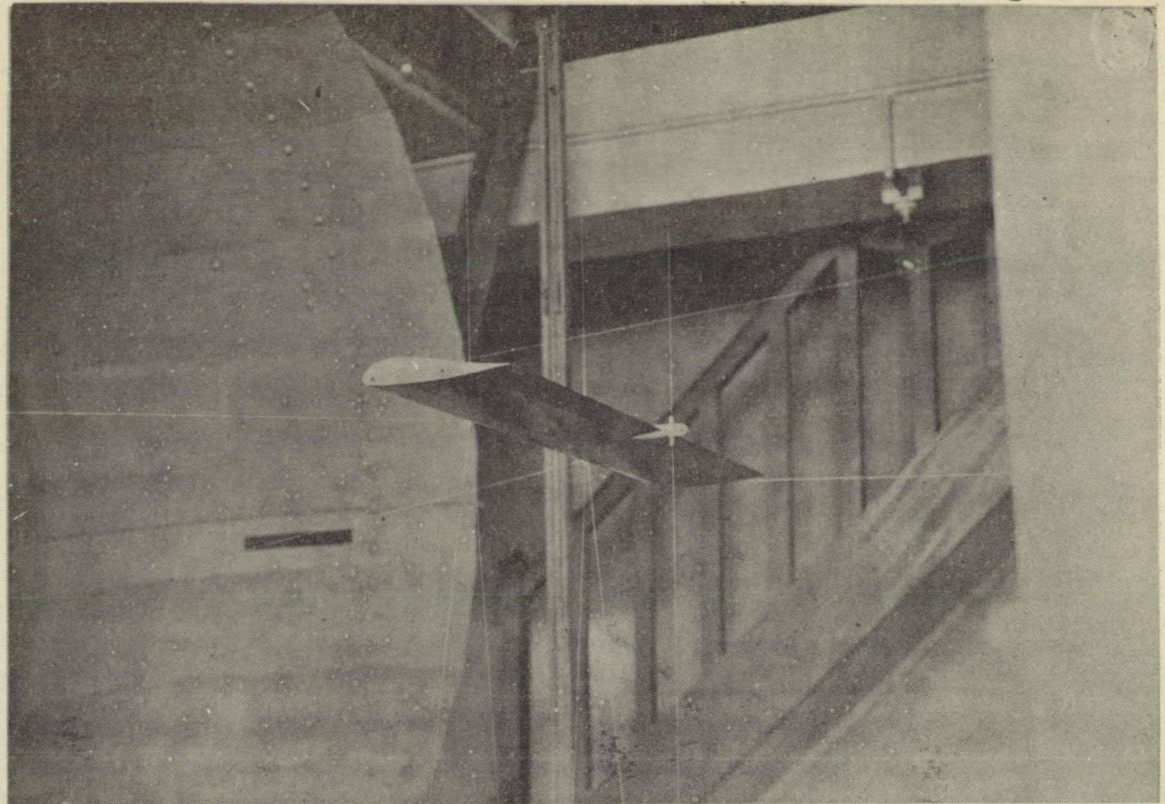

Fig.5

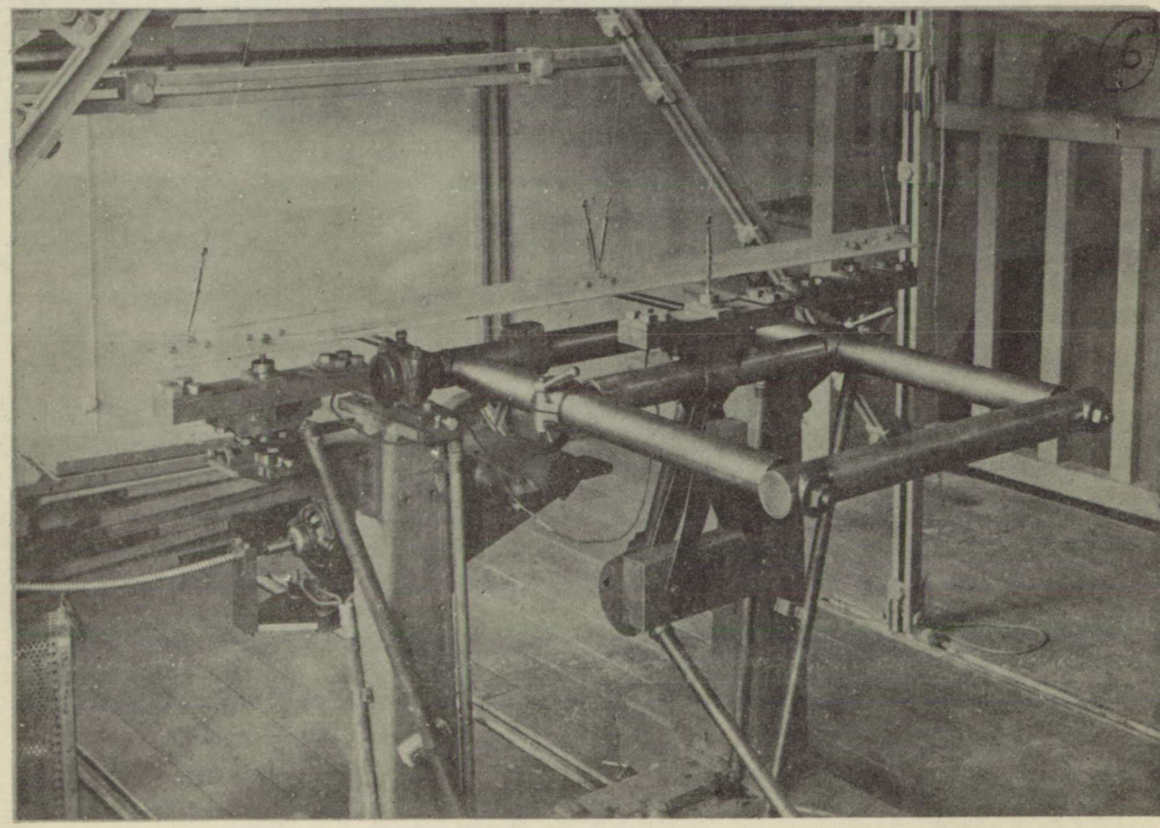

Fig.6

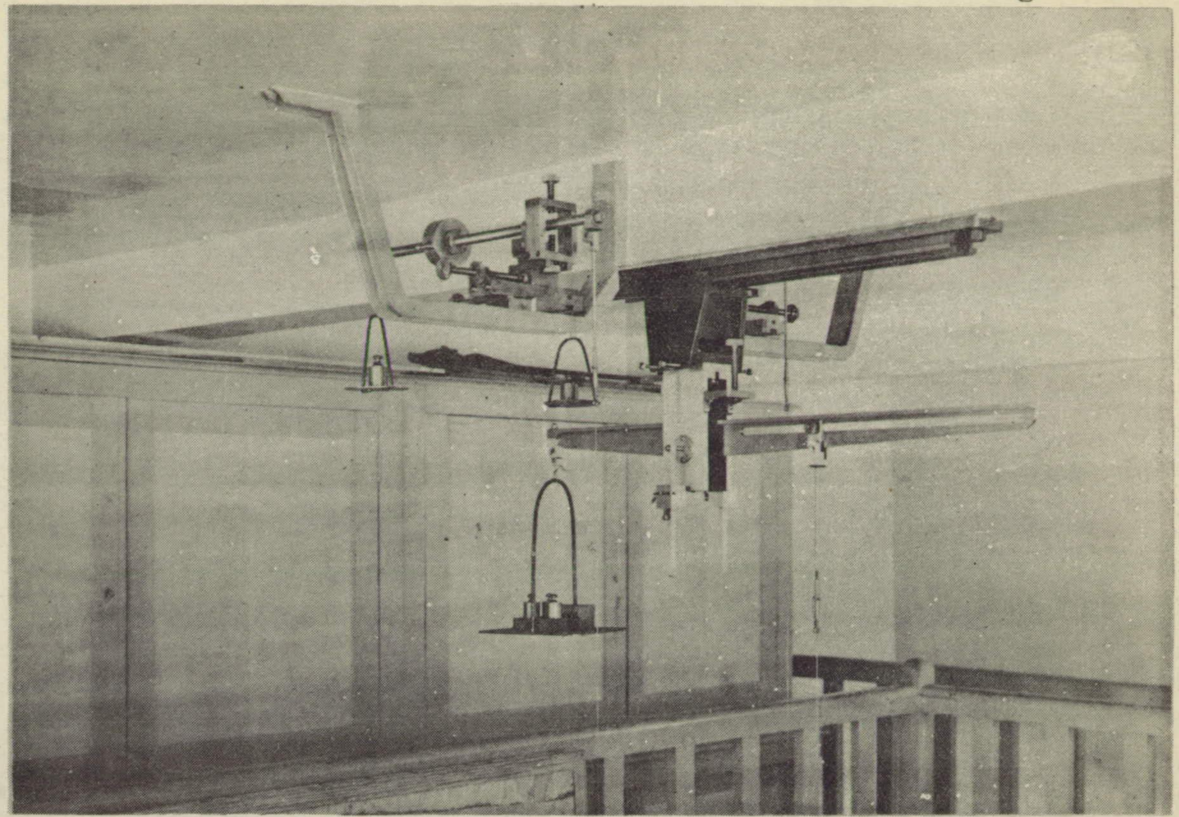

Fig.7

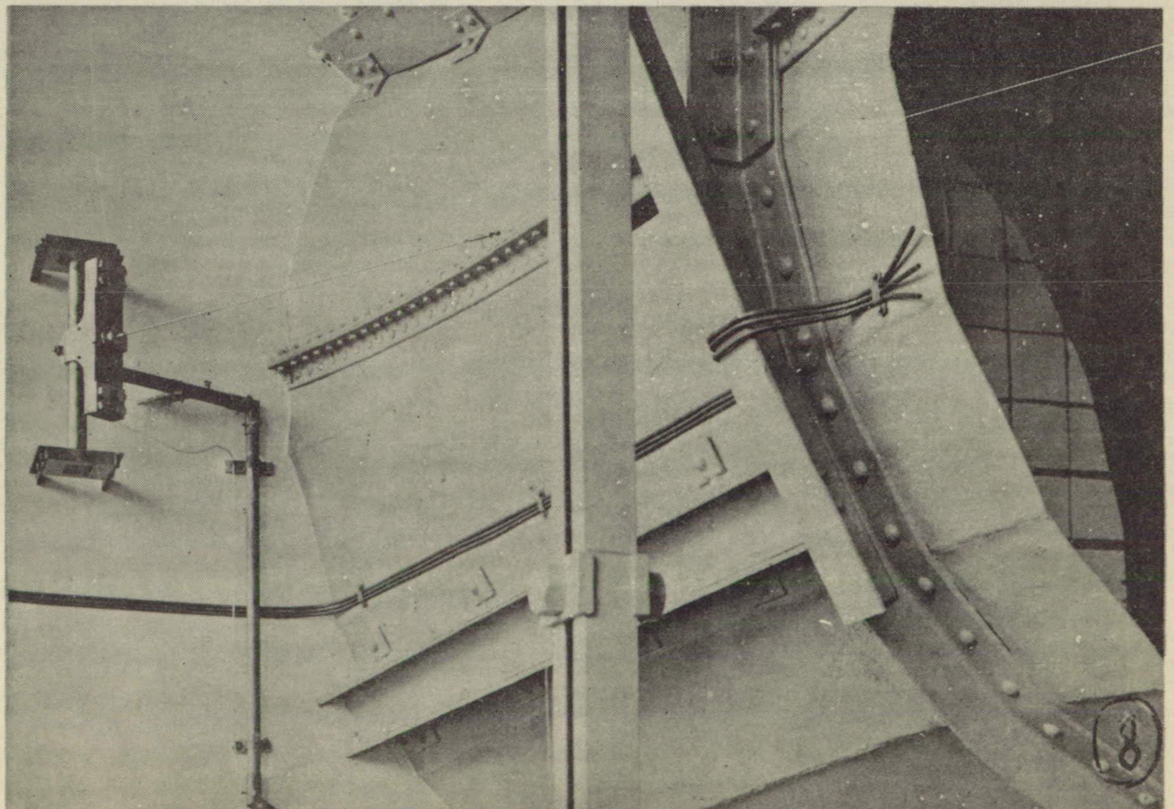

Fig.8

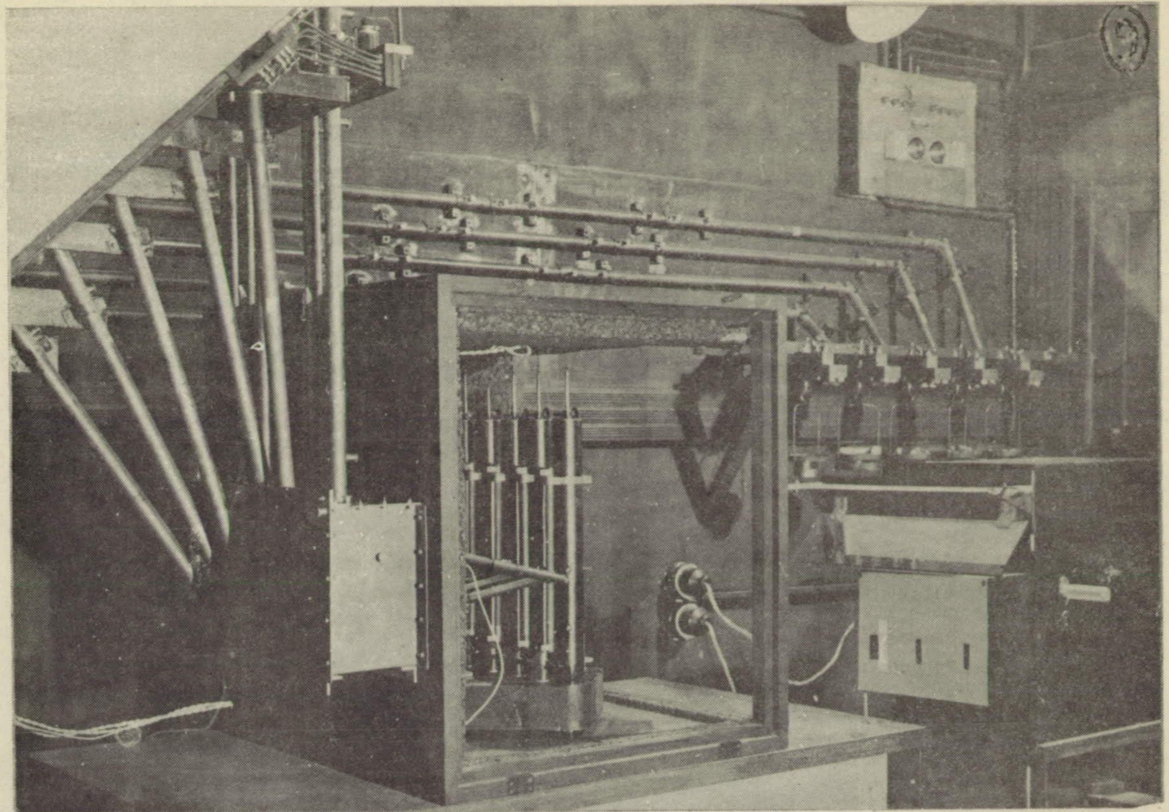

Fig.9

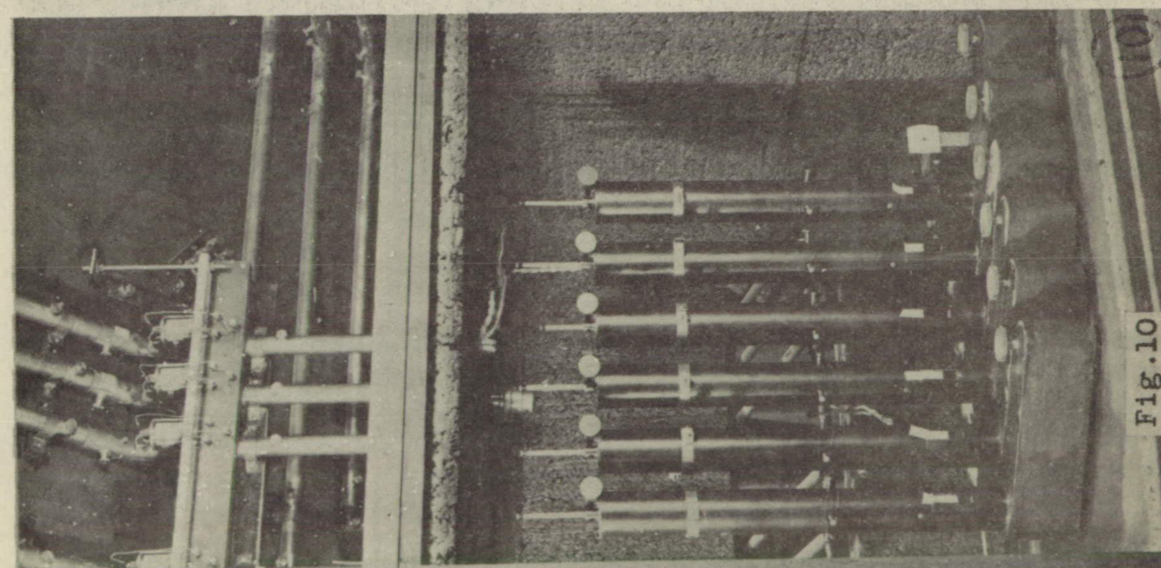

Fig.10

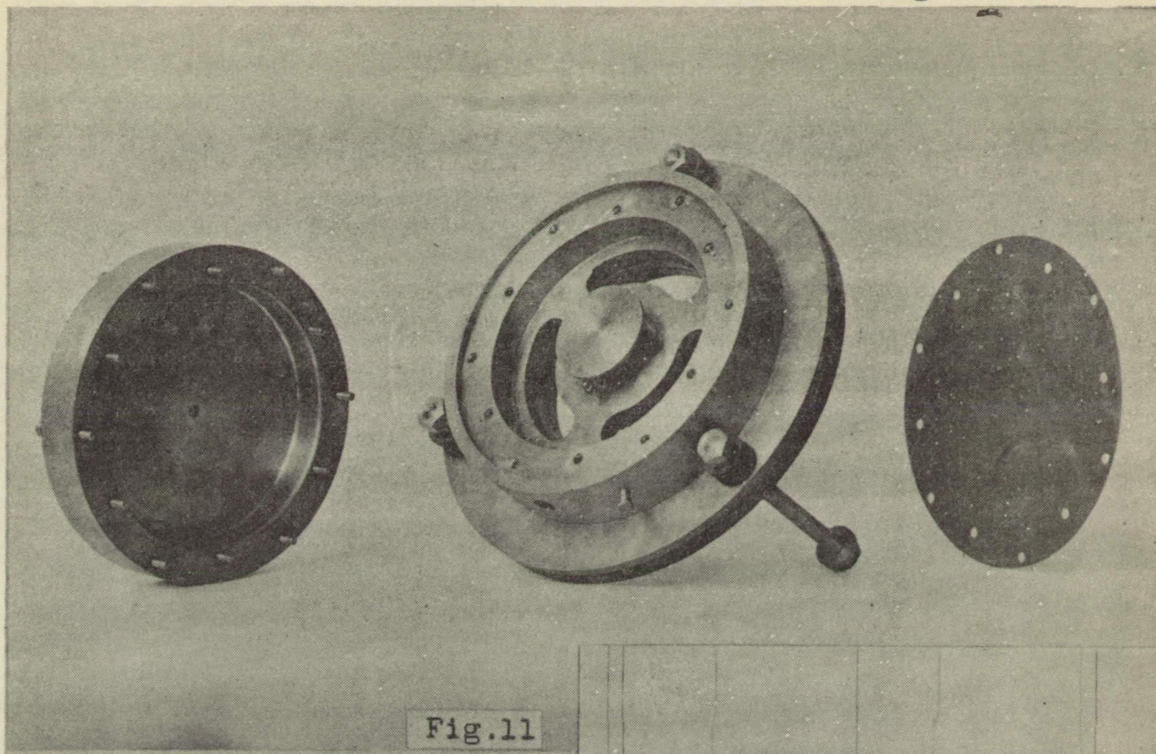

Fig.11

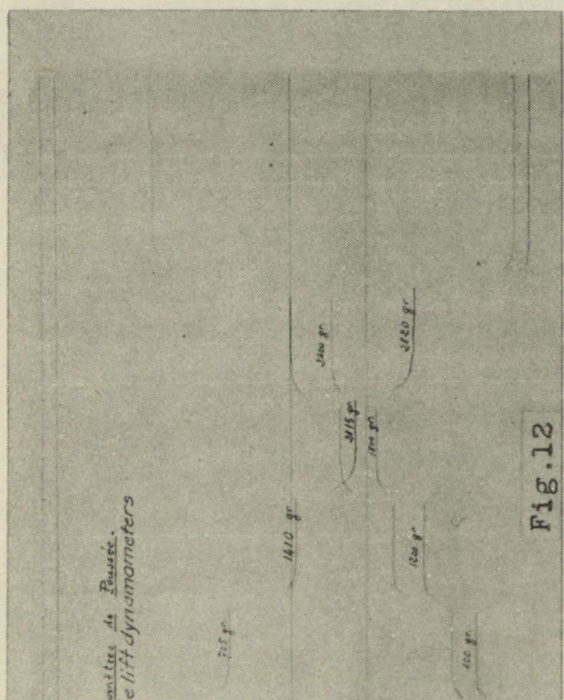

Fig.12

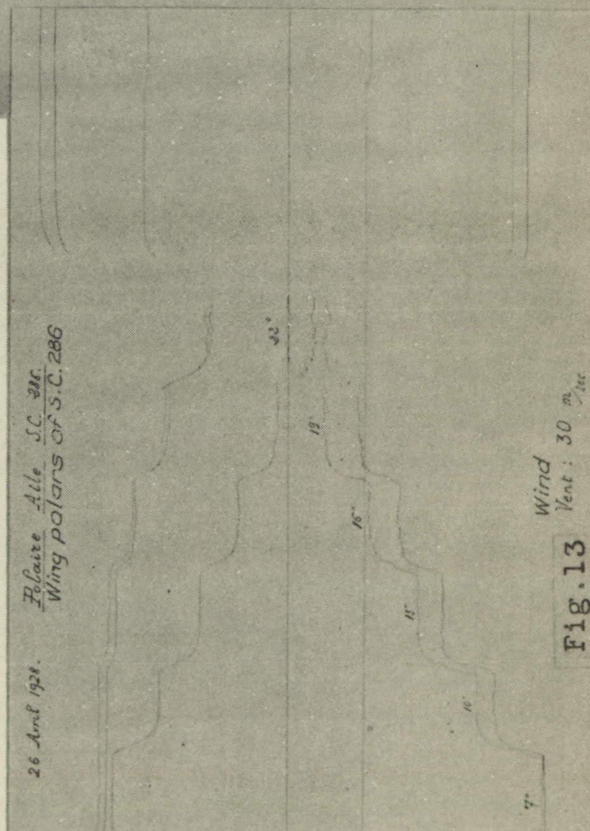

Fig.13